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Comment on "Pulsar kicks via spin-1 color superconductivity"

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In a recent Letter [1], Schmitt, Shovkovy, and Wang have proposed a new mechanism to explain the observed velocities of pulsars. Unfortunately, the mechanism is not viable.

The proposed explanation is based on anisotropic emission of neutrinos from a cooling neutron star at temperatures as low as $T \lesssim 0.1$ MeV, some $10^3 - 10^6$ yr after the supernova explosion. The anisotropy is supposed to develop only after the nuclear matter undergoes a phase transition to color superconductivity, which happens at a temperature well below 0.1 MeV, tens of thousands years after the supernova explosion.

However, the neutrino emission is negligible after the first minute since the onset of the supernova. Most neutrinos are emitted during the first $10 - 15$ seconds, and almost none are produced at times after 50 seconds, when the neutrino charged current mean free path becomes longer than the size of the neutron star [2]. When a neutron star temperature is as low as 0.1 MeV, its entire thermal energy $E_{_T} \sim 10^{48}$erg is smaller than the kinetic energy $E_{_K} \sim 10^{49}$erg of a pulsar moving with velocity 10^3km/s. Therefore, in any case, the pulsar kicks must originate at some earlier times.

One could ask, however, whether the proposed pulsar kick mechanism could possibly work if the phase transition happened at an earlier time, while the neutron star is emitting neutrinos. Unfortunately, the answer is no, because there is an additional fatal flaw in this mechanism. Neutrinos produced in an approximate thermal and statistical equilibrium diffuse out isotropically, even if the production cross sections and scattering amplitudes are anisotropic [3]. Neutrinos produced deep in the core of a neutron star with some initial anisotropies, whatever the origin, quickly isotropize through scattering, and their emission becomes isotropic. Hence, they cannot give the pulsar a kick. This no-go theorem [3] can be avoided if some of the neutrinos are out of equilibrium, or free-streaming. Examples include ordinary neutrinos outside one of the neutrinospheres [4], sterile neutrinos [5], Majorons [6], *etc.* All of these represent viable possibilities for the origin of the pulsar kicks. In particular, a sterile neutrino with mass is the keV range is an intriguing possibility because the same particle could be the cosmological dark matter [5, 7].

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